REPORT No. 37

FABRIC FASTENINGS.

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The study of aeronautical fabrics has naturally led to a consideration of the best methods of attaching and fastening together such materials. The following group of experiments does not completely cover this subject, but it is believed that the results are of practical value and that they may serve to indicate further lines of research into the stress distribution in built-up fabrics.

METHODS OF FASTENING WING FABRICS.

The supposed failure of the fabrics on the Bristol and De Haviland planes necessitated an investigation of stresses in the fabric during flight. The result proved conclusively that the failures were not what might properly be called fabric failures, but were caused by the lacing cords pulling through the upper fabric and by the failure of the lacing cords due to chafing.

The method of attaching the upper fabric to the wing employed at that time would appear to be very poor engineering. The total load on an area of fabric defined by the distance between lacings and the width of a bay concentrated on a very small area of fabric defined by the bearing surface of the lacing cord. The fabric, considering it to be supported along the rib, has a factor of safety of from 9 to 10. Obviously, the factor of safety at the lacing points is extremely low and conditions of abnormal flight might readily tear the fabric at these places of support. This condition was exaggerated by high vibratory stresses. Test specimens from the wing fabric of the planes that failed showed that the fabric itself had not weakened nor did it show any measurable indications of change in properties.

The Bureau of Standards suggested that a corded tape be put on the surface of the fabric along the rib and that it be so doped that a good bond would exist between the fabric and the tape. The lacings should then be placed over the cord tape at intervals of not more than 4 inches. The wind friction tape should then be placed on. This method of reinforcing has since been tried out in service tests and found to eliminate the trouble.

The structure of the reinforcing tape finally decided upon was:

Weight per linear yard............ounces..	0.24
Total warp ends............	14
Filling threads............	24

Every other filling thread allowed to loop about $\frac{1}{8}$ inch from edge warp yarns.

Yarn number, warp............	17/3/4
Yarn number, filling............	18/2
Tensile strength of warp............pounds..	146

It may readily be observed that the advantages of this tape are:

1. It presents a suitable bearing surface for the lacing cords, preventing them from tearing through due to tension stresses.

2. It has less stretch than the fabric and hence carries practically all of the load along the rib direction and transmits it to the lacings, thus preserving the factor of safety of the fabric

The resistance to the cord pulling out when the fabric was placed on the bias and when placed on straight was determined as follows:

The standard grade A cotton and grade A linen as used by the Signal Corps were stretched on frames under constant tension and coated with two coats of an approved acetate dope. Regulation linen lacing cords were placed in the fabric at an angle of approximately 45° to the warp with the two ends projecting from one side with ½ inch on centers of the cords. Two additional coats of dope were then applied.

The same fabrics were prepared similarly with the exception that the material was reinforced by strips of the same fabrics placed on the stretched fabrics before putting in the lacing cords.

The specimens were placed in the jaws of the testing machine and tension necessary to pull the cords through the fabric was noted.

Sample.	Not reinforced, cord 45° angle to warp.	Reinforced, cord 45° angle to warp.	Cord across—		Reinforced, cord across.	
			Warp.	Filling.	Warp.	Filling.
Standard A cotton	22.1	33.65	28	19	28	28
Standard A linen	24.5	35.1	21	20	30	26

It will be noted that there is very little difference between the resistance of the fabric to the pulling out of the cords whether they are placed on the bias or not. The warp of these fabrics has practically twice the stretch of the filling, and there is very little difference between the strength of the warp and filling yarns. As a result, it is logical to expect that the warp yarns were carrying very little of the load at the time the filling yarn ruptured when the cord is placed on the bias. Considering this, there can be no object in placing the present fabric on the bias, from the consideration of either the lacings or the fabric between the wings.

LACING CORDS.

Experiments were made to determine the strength of lacing cords and whether or not cotton cords could be substituted for the linen cords. Hence, the properties of a lacing cord which are of interest are:

1. Tensile strength.
2. Resistance to abrasion.
3. Resistance to repeated stresses.

An examination of the stresses causing rupture of a lacing cord under flight conditions will lead to the conclusion that a cord fails because it is weakened by rubbing against the rib and because it is subjected to rapid vibratory stresses.

TABLE A.

	Tensile strength.		Abrasion (fray).		Tension (fray).	
	Unwaxed.	Waxed.	Unwaxed.	Waxed.	Unwaxed.	Waxed.
Linen, 8030, 6-cord	22.0	....	3,000 x 2	10,000 x 2	275	860
Linen, 8031, 9-cord	26.3	26.5	4,000 x 2	8,000 x 2	590	2,000
Linen, 8031, 9-cord	22.7	22.6	5,500 x 2	9,000 x 2	430	1,300
Cotton, 20/3/4/3	21.2	21.6	9,000 x 2	10,000 x 2	1,560	2,950
Cotton, 20/3/3/3	20.2	19.3	4,000 x 2	9,000 x 2	1,100	2,700

Results given in Table A were obtained from tests to determine the relative resistance of the cords to stresses occurring during flight conditions.

Tensile strength.—The tensile strength of the linen and cotton lacing cords are given in the table. Owing to the fact that the quantity of linen cord was very much limited, it was impossible to make as large a number of tests with each cord as was desirable.

The tensile strength was determined by breaking a single strand.

The effect of waxing is practically negligible so far as these tensile strength tests indicate, for no consistent difference in the strength of waxed and unwaxed cords was observable. This, however, is about what we would expect.

The strength of a cord impregnated with paraffin is somewhat less. Ordinary beeswax was used in the tests.

Abrasion (fray).—This fraying test was made by allowing the cord under test to rub upon a spruce wood surface, the line of the thread being perpendicular to the grain of the wood.

A spool of spruce was mounted on an axis (parallel to grain). The cord was fastened at one end and brought over the spool, carrying a 5-pound weight at the other end. The spool oscillates through approximately 90° at 200 revolutions per minute. This means that the string is rubbed 200 times per minute in each direction of its length or 400 rubs in all. The operation was continued in each case until the cord broke. The number of rubs before breaking is recorded in data.

Waxing greatly improves resistance to abrasion in both linen and cotton cords. The waxing effect is greater in the linen than in the cotton cords.

Sources of error.—

Uneven wearing of the spruce surface.

Heat produced, due to friction.

Difference in twist in the linen cords.

Tension (fray).—An apparatus was improvised to apply a force to the cord (longitudinally) at regularly repeated intervals. The force used was approximately 25 pounds and gave the cord a jerk 200 per minute. This causes the fibers to suddenly draw close together, as the load is applied, then to spring apart as the load is removed. The friction thus produced results in a wearing of the individual fibers until finally a break occurs.

If this alternate separation and drawing together is prevented or diminished, as is the case when the cord is waxed, the wearing due to friction is much reduced and the cord does not break so soon. The data gives the total number of jerks before the break occurs.

Here waxing seems to add to the life of the cord, the effect being more marked with the linen than with the cotton cords.

All these experiments and accompanying data serve merely as comparative tests.

SUMMARY.

From these tests it may be concluded that—

1. The unwaxed cotton cords are materially better resistors of abrasion fray than the unwaxed linen.

2. The waxen linen and cotton have practically the same resistance to abrasion fray.

3. The waxed or unwaxed cotton cords are materially better than the waxed or unwaxed linen as a resistor of tension fray.

FASTENING OF TRAILING EDGE.

The sewing together of the fabric at the trailing edge of a wing appeared to be a laborious and expensive operation, and from preliminary tests made at the factories under flight conditions it appeared that lapped and pasted fastening was satisfactory. The following tests were made to determine the efficiency of the pasted lap and the sewed trailing edge seam.

A sample of fabric doped and painted taken from trailing edge of plane was tested by passing the fabric around a $\frac{3}{16}$-inch rod and clamping the two ends in the pulling clamps of the testing machine. The middle of the pasted joint was directly over the rod. The speed of testing was 6 inches per minute. The specimens were $\frac{1}{2}$ inch wide.

The tensile strength of the doped fabric was 247 pounds per $1\frac{1}{2}$ inches.

The pasted joint of the pasted seam gave way.

Further tests in the same manner were conducted on grade A cotton and grade A linen. Samples were prepared in the following manner for both grades.

1. Samples were folded back, butted against each other, and sewed with a "baseball" stitch of linen thread approximately 30 lea. The stitches were $\frac{1}{4}$ inch apart. These were made over a false trailing edge and doped with two coats of dope. The frayed surface tape was put on with the third coat and later a fourth coat added. The warp of the fabric was perpendicular to trailing edge.

2. Samples were prepared by lapping the fabric over a false trailing edge with 1 inch ± overlap. This was pasted with the first coat of dope. The surface tape was put on with the third coat and a fourth added. The warp of the fabric was perpendicular to trailing edge.

3. The surface tape was prepared by cutting the material $2\frac{1}{2}$ inches wide and raveling $\frac{1}{4}$ inch on each side. Tape with the warp parallel to its length and with filling parallel to its length was prepared. The usual method with the warp parallel to its length is put on the trailing edge such that the filling of the tape is parallel to the warp of the wing fabric. The filling tape has the warp parallel to the warp of the wing fabric.

Sample designation.	Tensile strength (pounds per $1\frac{1}{2}$ inches).		Remarks.	
	Sewed.	Pasted.	Sewed.	Pasted.
LINEN.				
Tape warp parallel to edge	306	193	F.	S.
Tape filling parallel to edge		203		F.
No tape	167		S.	
COTTON.				
Tape warp parallel to edge	281	146	F.	S.
Tape filling parallel to edge	260	233	F.	F.

F—Fabric gave way.
S—Stitching or sticking gave way.

In view of the fact that the strength of the pasted joint is much lower than the strength of the sewed joint, it is concluded that this method of fastening is not good. This difference would probably be emphasized if the dope deteriorated. In the case of the pasted seam the number of tacks left in would proportionately increase its resistance to approximately equal the strength of the sewed seam with a number of tacks equal to the number of stitches.

For training planes, which are painted with light protecting medium and in which the stresses of flight are low, the pasted method would be satisfactory.

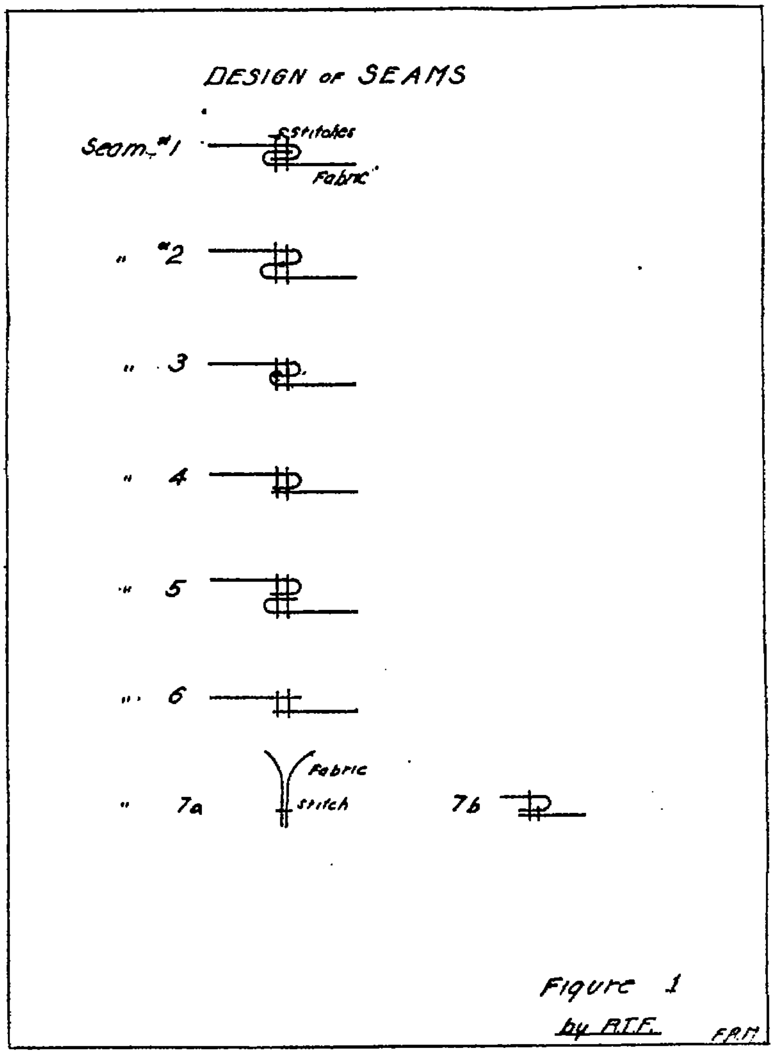
The effect of the properties of the surface tape as influencing the strength of the joint is interesting. In the case of the pasted joint, a tape the warp of which is parallel to the warp of the wing fabric materially reduces the shearing action on the dope paste between the tape and the fabric and consequently increases the strength of the joint.

In the case of the sewed seam, a tape the warp of which is parallel to the warp of the wing covering reduces the strength of the joint. This is probably due to the fact that more of the load is carried by the stitchings, due to the excessive stretch of the warp of the tape at any load as compared to the stretch of the filling.

SUMMARY.

For a sewed joint, at the trailing edge, of straightaway fabrics, the warp of the tape should be parallel to trailing edge.

For a pasted joint, of similar use, the filling of the tape should be parallel to trailing edge to obtain the best results.



The above assumes that the warp of the tape has much more stretch than the filling.

From this it might be assumed that a bias joint should be covered with a bias surface tape.

AIRPLANE FABRIC SEAMS.

In covering the wings of a plane, it is necessary to sew several widths of the fabric together to obtain the required width. The seams having less stretch than the fabric will under certain conditions of stress carry the major portion of the load and consequently must be proportionately stronger.

The three important factors to be considered in determining the strongest type of seam applicable for this purpose are, first, the method of overlapping the edges of the cloth; second, the strength of the sewing thread; and third, the number of stitches per inch.

With the available sewing machines there are six ways in which the cloth may be overlapped, which are shown in figure 1.

The tensile strength of the seam was determined by means of an inclination balance type of testing machine. The seam was approximately midway between the clamps and perpendicular to the line of stress. Clamps were 1 inch wide and the distance between clamps was 1 inch The rate of separation of the clamps was 12 inches per minute.

The following table shows the strength of the six types of seams in both the undoped and doped state.

Tensile strength, in pounds.

UNDOPED.

[Seam designation.]

	A.	B.	C.
1	84 S	81 F	79 S
2	81 S	77 F	79 F
3	79 F	79 F	78 F
4	72 F	74 F	78 S
5	87 F	78 F	77 S
6	67 F	72 F	75 F

DOPED.

	A.	B.	C.
1	106 S	120 F	93 F
2	111 S	119 F	94 F
3	114 S	116 F	107 F+S
4	104 S	114 F	101 S
5	111 S	118 F	104 S
6	97 S	116 F	106 S

F=Fabric failed.
S=Stitches failed.

Seam A was sewed with "A" white silk, 16,000 yards per pound and having a tensile strength of 3 pounds per single strand.

Seam B was sewed with "B" white silk, 10,000 yards per pound and having a tensile strength of 5 pounds per single strand.

Seam C was sewed with No. 30, O. N. T. cotton having a tensile strength of 3.5 pounds.

The seams were sewed with two parallel lines of stitches ¼ inch apart and with 10 stitches per inch.

The comparative strength of the seams made with different numbers of stitches per inch was determined as in the previous case.

The following table shows the strength of the seam with five different lengths of stitches:

Fabric.	6 stitches.	8 stitches.	10 stitches.	12 stitches.	15 stitches.
Undoped	68	76	75	78	74
Doped	77	93	97	102	95

SUMMARY.

An examination of the structure of the seams shows that the number of threads stressed is independent of the method of lapping the fabric. From this and the test results, it is concluded that any one of the six-seam designs is equally strong.

The seam No. 4 made up in the two successive steps, as shown under 7, appears to be the most satisfactory.

The seam has the advantage of being easily and uniformly made, is strong, and presents an edge to be doped which will not curl.

Ten stitches per inch using the threads experimented with is the most satisfactory number.

REINFORCED BALLOON CLOTH.

Many attempts have been made to strengthen and increase the tearing resistance of balloon cloth by means of reinforcing. The most common method has been to introduce a heavy warp and filling end about an inch apart having a much higher strength than the surrounding yarn. A tear starting between the reinforcings would supposedly tear to the nearest reinforcing in line of the tear and stop. This method was not satisfactory, due to the uneven surface taking up an uneven coating of rubber when the gas film was applied.

Another method which has met with some success has been to sew reinforcing tape on the surface of the fabric parallel to the warp and filling so that squares of about 8 inches were formed.

To determine the strongest type of reinforcing tape the following tests were made:

This method may be considered as an attempt to approximate a shock tear. The cloth was stretched on a light, wooden, rectangular frame under enough tension to take out the wrinkles and was suspended from a spring balance. A square 2 inches on a side was marked near the top of the frame. Three sides of the square were cut and the piece allowed to hang down. A 50-pound weight was attached to the hanging strip and the fabric caused to tear by reason of the weight dropping. The force transmitted by the tearing fabric, as shown by the deflection of the spring balance, was plotted autographically against the motion of the falling weight.

The warp was in the perpendicular or horizontal position, depending upon which system of threads was being torn. The cut strip was allowed to hang down on the seam side of the fabric and over the side of the fabric having no seam.

The second method was a modification of the first, in that the same procedure was followed with the exception that the tearing was induced by placing the material between the clamps of the conventional type for tensile strength testing. The lower clamp moved at the rate of 5 inches per minute.

This method is believed to be more nearly indicative of the actual performance of the fabric.

The fabric was clamped in the circular container 30 centimeters in diameter with the fabric free to deflect by reason of applied air pressure.

The material was stressed to very nearly its bursting pressure and a cut made at the center point, which started a tear. The directions and lengths of the tears were noted.

Kinds of reinforcing tested were:

Sample A.—Straight seam (tape), parallel to warp and filling.

Sample B.—Bias tape, parallel to warp and filling.

Sample C.—Straight tape, bias to warp and filling.

Sample D.—Bias tape, bias to warp and filling.

Results of tests.—When the cut strip was allowed to hang over the side of the fabric having no tape (seam) and the fabric torn according to methods one and two, the effect of the tape or seam was not noticeable.

In the case of allowing the cut strip to hang down over the seam and tearing according to the first method, the fabric tore to the tape and then followed the stitching of the tape until the strip tore off.

Sample A.—The tear started in the direction of filling and across the warp ends, tore down to the reinforcing tape, broke the stitches holding the tape and continued. The tear across the filling ends acted in the same manner.

Sample B.—The tear across the warp ends tore to reinforcing tape and then followed the tape until the strip tore off. The tear across the filling ends tore to the tape reinforcing, broke the stitches and then continued.

Sample C.—The tear across both warp and filling ends tore to the tape, broke the stitches and continued.

Sample D.—The tear across both warp and filling ends tore to the reinforcing tape then followed the stitches until the strip tore off.

The sample B with bias reinforcing tape sewed parallel to warp and filling gave the best results as the load required to tear the strip off at the reinforcing was slightly greater than in any of the other methods of reinforcing.

The results of tearing by these methods are as follows:

Sample A.—Tear ran through seam.

Sample B.—Tear stopped at tape (seam).

Sample C.—Tear ran under seam when intersection of two seams were at center of clamped fabric.

The tear followed the seam when the intersection of two seams was off center.

Sample D.—Tear ran under seams.

From the above experiments it may be assumed that the method illustrated in Sample B (bias tape parallel to warp and filling) is the most efficient.

BALLOON FABRIC SEAMS.

The Bureau of Standards, in cooperation with the joint Army and Navy Aircraft Board, have been experimenting with various methods of making seams in the envelopes of balloons, the desired object being a seam having the necessary strength and gas tightness and having the minimum weight. This report deals with the strength of the seams.

The samples tested were made by the B. F. Goodrich Co., and the Goodyear Tire & Rubber Co., each company furnishing—

Samples of finished fabric without seams.
Samples of seams stitched and cemented, but not taped.
Samples of seams cemented and taped but not stitched.
Samples of seams cemented, taped, and stitched.

The samples submitted were two-ply fabric, one ply biased at approximately 45° to the other.

The fabrics were overlapped $\frac{3}{4}$ inch in all cases, and when sewed had two parallel lines of stitches approximately $\frac{1}{2}$ inch apart.

The Goodrich seams were sewed with silk sewing thread, five stitches to the inch, on a lock-stitch machine. The tape used to cover one side of the seam was straight and 2 inches wide. The tape used to cover the reverse side of the seam was straight and $1\frac{1}{2}$ inches wide.

The Goodyear seams were sewed with cotton sewing thread, seven stitches to the inch, on a chain-stitch machine. The tape used to cover both sides of the seam were bias and $1\frac{5}{8}$ inches wide.

Method of test—

1. Samples of each fabric and the several different seams were tested and determinations of the bursting properties were made.
2. Strips of the plain fabric 2 by 6 inches were cut parallel to the warp and filling of each ply of cloth and the tensile strength determined.
3. Strips with the seam in the center were cut 3 by 6 inches, the long side of the strip parallel to the seam and the tensile strength determined.
4. Samples of the sewing thread were tested and determination of the tensile strength were made.

Bursting test.—The fabric was placed under the annular ring of the bursting apparatus with the center of the seam coinciding with a diameter of the ring and the fabric subjected to a uniformly increasing air pressure. The deflection at the central point of the fabric or seam was plotted autographically against the pressure necessary to produce the deflection. A rubber diaphram was used under the fabric to prevent leakage of air.

Tensile strength tests.—The strips cut in methods 2 and 3 were placed in the clamps of a conventional inclination balance type of testing machine with 3 inches between clamps and the strips were caused to rupture by separating the clamps at a rate of 12 inches per minute.

The sewing thread was broken on a conventional inclination balance type of testing machine with 6 inches between jaws.

Results of tests.—The results of the determination of bursting tests are shown in Table I.

The results of the determination of tensile strength tests on the strips are shown in Table II.

The results of the determination of tensile strength tests on the sewing thread are shown in Table III.

Value of tests.—The bursting tests show the behavior of the material when it is subjected to a uniformly distributed pressure and can, therefore, be taken as a laboratory method of determining the behavior of the fabric or seam when the material is used in an inflated spherical balloon.

The deflection at any pressure shows the degree of tautness of the fabric or seam and the pressure necessary to rupture the fabric or seam may be used as a valuable index to the factor of safety.

The tensile strength tests on the fabric show the strength of individual cloths which make up the finished fabric.

The tensile strength tests on the seams show the amount of stress necessary to rupture the seam.

Discussion of results.—Table I shows the average results of the bursting tests on the fabrics and seams.

The small size of the Goodyear plain fabric samples precluded a satisfactory bursting test and the result shown is not believed to be a fair measure of their ability to resist pressure. The results of the bursting test would indicate that the Goodrich seam is stronger than the Goodyear. This may be due to the slightly higher tensile strength of the Goodrich fabric and to the wider tape used in covering the Goodrich seams.

The difference between the surface tension in the seams which were cemented and stitched and the surface tension in the plain fabric would indicate that stitching had weakened the fabric.

The slight difference between the surface tension of the cemented and taped seam and the cemented, taped, and stitched seam of the Goodyear fabric would indicate that the stitching added very little strength to the seam. A comparison of the corresponding data on the Goodrich seam would indicate that the stitching added strength.

Table II gives the average results of the determinations of the tensile strength of the plain fabric per inch width, the average tensile strength of the seams, the weight in ounces per square yard of plain fabric, and the weight in ounces per linear yard of the seams.

A comparison of the tensile strengths of the fabrics shows the Goodrich fabric to be slightly stronger than the Goodyear fabric.

In stressing the Goodyear cemented and taped seam, also the cemented, taped, and stitched seam, the seams gave way at 127 pounds and 175 pounds, respectively, after which the fabric on either side of the seam carried the load. The final rupture point is shown in Table II.

It is not thought that the final rupture point should be considered in comparing the results of the two makes of seams, as the seam itself had ruptured previous to this point.

Table III shows the comparative tensile strength of the sewing threads used in making the seams. The thread used by the Goodrich Co. is stronger in all cases.

It is not thought that the difference between the use of the lock stitch and the chain stitch influenced the results to any appreciable extent.

SUMMARY.

From the results of these tests it would appear that the stitching of the seam is not necessary.

It is evident that the study of seams should be extended to include the effect of turn of load application, and the flow of the cement.

TABLE I.

Make-up of sample	Goodyear.			Goodrich.		
	P.	D.	ST.	P.	D.	ST.
Plain fabric	6.0	1.64	35.1	12.7	1.95	60.1
Seam cemented and stitched	8.7	1.57	53.1	13.25	2.15	61.0
Seam cemented and taped	10.05	1.71	57.4	15.2	2.26	68.6
Seam cemented, taped, and stitched	9.75	1.60	58.4	15.1	2.06	74.5

P—Pressure in pounds per square inch.
D—Deflection in inches of the center point of fabric.
ST—Surface tension in pounds per inch through the center of the fabric at time of rupture.

TABLE II.

Make-up of sample.	Goodyear.				Goodrich.			
	Warp (pounds per inch).	Filling (pounds per inch).	Strength of seam.	Weight (ounces per square yard).	Warp (pounds per inch).	Filling (pounds per inch).	Strength of seam.	Weight (ounces per square yard).
Plain fabric				11.2				10.1
Parallel cloth of plain fabric	50.3	52.0			58	58.8		
Bias cloth of plain fabric	52.1	60.8			51.3	56.1		
Seam cemented and stitched			139.6	.49			150.6	.50
Seam cemented and taped			240.3	1.42			177.3	1.47
Seam cemented, taped, and stitched			244.0	1.45			181.6	1.49

TABLE III.

Sample spool of thread marked	Number 30.	Number 50.	Number C-9R.	Number C-10.	Number C-11½.
Average breaking strength, pounds	3.31–3.76	2.2–2.27	4.34	4.82	5.65–5.70